JC19 Rec'd/PCT/PTO 17 JUL 2001

FORM PTO-1390 (REV. 5-93) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER 10191/1860
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371	U.S. APPLICATION NO. (If known, see 37 CFR 1.5) 09/889418

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED:
PCT/DE00/04008	**10 November 2000 (10.11.00)**	**17 November 1999 (17.11.99)**

TITLE OF INVENTION
METHOD FOR SHIFTING THE INSTANT OF COMMUTATION FOR A SENSORLESS AND BRUSHLESS DIRECT-CURRENT MOTOR AS WELL AS A SYSTEM FOR IMPLEMENTING THE METHOD

APPLICANT(S) FOR DO/EO/US
Joerg SUTTER, and Wolfgang SCHWENK

Applicants herewith submit to the United States Designated/Elected Office (DO/EO/US) the following items and other information.

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) immediately rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☐ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☒ has been transmitted by the International Bureau.
   - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   - a ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☐ have. been transmitted by the International Bureau.
   - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   - d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)) (unsigned).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A **FIRST** preliminary amendment.
14. ☒ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information: International Search Report (translated), and PCT/RO/101.

EXPRESS MAIL NO.: EL244504926US

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U.S. APPLICATION NO. if known, see 37 C.F.A.1.5 09/889418	INTERNATIONAL APPLICATION NO PCT/DE00/04008	ATTORNEY'S DOCKET NUMBER 10191/1860

17. ☒ The following fees are submitted:

Basic National Fee (37 CFR 1.492(a)(1)-(5)):

Search Report has been prepared by the EUROPEAN PATENT OFFICE or JPO $860.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) $690.00

No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) $710.00

Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO $1,000.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) $100.00

				CALCULATIONS	PTO USE ONLY
ENTER APPROPRIATE BASIC FEE AMOUNT =				$ 860	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				$	
Claims	Number Filed	Number Extra	Rate		
Total Claims	12 - 20 =	0	X $18.00	$ 0	
Independent Claims	2 - 3 =	0	X $80.00	$ 0	
Multiple dependent claim(s) (if applicable)			+ $270.00	$	
TOTAL OF ABOVE CALCULATIONS =				$ 860	
Reduction by ½ for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).				$	
SUBTOTAL =				$ 860	
Processing fee of $130.00 for furnishing the English translation later the ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$	
TOTAL NATIONAL FEE =				$ 860	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property +				$	
TOTAL FEES ENCLOSED =				$ 860	
				Amount to be: refunded	$
				charged	$

a. ☐ A check in the amount of $__________ to cover the above fees is enclosed.

b. ☒ Please charge my Deposit Account No. 11-0600 in the amount of **$860.00** to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 11-0600. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

By: [signature] (Reg. No. 41,172)

Richard L. Mayer

SIGNATURE

SEND ALL CORRESPONDENCE TO:
Kenyon & Kenyon
One Broadway
New York, New York 10004

Richard L. Mayer, Reg. No. 22,490

NAME

CUSTOMER NO. 26646

DATE 7/17/01

[10191/1860]

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s)	:	SUTTER et al.
Serial No.	:	To Be Assigned
Filed	:	Herewith
For	:	METHOD FOR SHIFTING THE INSTANT OF COMMUTATION FOR A SENSORLESS AND BRUSHLESS DIRECT-CURRENT MOTOR AS WELL AS A SYSTEM FOR IMPLEMENTING THE METHOD
Art Unit	:	To Be Assigned
Examiner	:	To Be Assigned

Assistant Commissioner
for Patents
Washington, D.C. 20231
Box Patent Application

PRELIMINARY AMENDMENT AND
37 C.F.R. § 1.125 SUBSTITUTE SPECIFICATION STATEMENT

SIR:

Please amend the above-identified application before examination, as set forth below.

IN THE SPECIFICATION AND ABSTRACT:

In accordance with 37 C.F.R. § 1.121(b)(3), a Substitute Specification (including the Abstract, but without claims) accompanies this response. It is respectfully requested that the Substitute Specification (including Abstract) be entered to replace the Specification of record.

IN THE CLAIMS:

On the first page of the claims, first line, change "What is claimed is:" to:

--What Is Claimed Is:--.

Please cancel original claims 1 to 9, without prejudice, in the underlying PCT Application No. PCT/DE00/04008.

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Please add the following new claims:

10. (New) A method for shifting an instant of commutation for a sensorless and brushless direct-current motor including stator windings fed by a multi-phase converter connection, comprising the steps of:

detecting the instant of commutation by comparing a voltage induced in a stator winding phase in which no current is applied to a reference voltage; and

changing the reference voltage in dependence upon at least one of a setpoint value of a rotational speed of the direct-current motor and a manipulated variable calculated from the setpoint value.

11. (New) The method according to claim 10, further comprising the step of:

shifting forward the instant of commutation with respect to time such that an optimum current waveform is achieved, the optimum current waveform being with respect to at least one of increasing a power and reducing a torque ripple.

12. (New) The method according to clam 10, further comprising the step of:

shifting the instant of commutation such that the reference voltage is raised in a shape of a parabola.

13. (New) The method according to claim 12, wherein:

with respect to a pulse width modulation of a current supplied to the stator windings, the parabola-shaped raising of the reference voltage begins at a pulse width modulation ratio of about 90 to 95%.

14. (New) The method according to claim 13, wherein:

the pulse width modulation ratio is 93%.

15. (New) The method according to claim 10, further comprising the step of:

adapting a current supply to individual stator winding phases in accordance with the manipulated variable in order to one of raise and lower the current supply accordingly.

16. (New) A system for shifting an instant of commutation, comprising:

a multi-stage converter connection, including:

an output stage control,

a commutation logic,

a phase selector, and

a phase discriminator;

a sensorless and brushless direct-current motor fed by the multi-stage converter connection;

a commutation detection element, including:

a first input supplied by the phase selector with an instantaneous value of a voltage induced in a non-energized phase, and

a second input supplied with a reference voltage for comparison;

a commutation shift element for changing the reference voltage in accordance with a specific curve; and

a manipulated-variable calculation element for supplying a manipulated variable to the commutation shift element as a function of a setpoint speed of the direct-current motor.

17. (New) The system according to claim 16, wherein:

in the commutation shift element, the reference voltage is changed in accordance with a parabola.

18. (New) The system according to claim 17, wherein:

the reference voltage is increased.

19. (New) The system according to claim 17, wherein:

with respect to a pulse width modulation of a current supply to individual stator winding phases of the direct-current motor, the reference voltage is increased in a parabola shape, starting from a pulse width modulation ratio of about 90 to 95%.

20. (New) The system according to claim 19, wherein:

the pulse width modulation ratio is 93%.

21. (New) The system according to claim 16, wherein:

the manipulated-variable calculation element computes the manipulated variable as a non-linear function of the setpoint speed of the direct-current motor, and

the manipulated variable is fed, on the one hand, as an input to the commutation shift element, and, on the other hand, to the commutation logic to adapt a current supply to stator winding phases of the direct-current motor.

Remarks

This Preliminary Amendment cancels original claims 1 to 9, without prejudice, in the underlying PCT Application No. PCT/DE00/04008. The Preliminary Amendment also adds new claims 10-21. The new claims conform the claims to U.S. Patent and Trademark Office rules and do not add new matter to the application.

In accordance with 37 C.F.R. § 1.121(b)(3), the Substitute Specification (including the Abstract, but without the claims) contains no new matter. The amendments reflected in the Substitute Specification (including Abstract) are to conform the Specification and Abstract to U.S. Patent and Trademark Office rules or to correct informalities. As required by 37 C.F.R. § 1.121(b)(3)(iii) and § 1.125(b)(2), a Marked Up Version Of The Substitute Specification comparing the Specification of record and the Substitute Specification also accompanies this Preliminary Amendment. Approval and entry of the Substitute Specification (including Abstract) are respectfully requested.

The underlying PCT Application No. PCT/DE00/04008 includes an International Search Report, dated March 29, 2001, a copy of which is submitted herewith.

Applicants assert that the subject matter of the present application is new, non-obvious, and useful. Prompt consideration and allowance of the application are respectfully requested.

Respectfully Submitted,

KENYON & KENYON

By: [signature] (Reg. No. 41,172)

Dated: 7/17/01

By: [signature]

Richard L. Mayer
(Reg. No. 22,490)

One Broadway
New York, NY 10004
(212) 425-7200

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[10191/1860]

METHOD FOR SHIFTING THE INSTANT OF COMMUTATION FOR A SENSORLESS AND BRUSHLESS DIRECT-CURRENT MOTOR AS WELL AS A SYSTEM FOR IMPLEMENTING THE METHOD

Field Of The Invention

The present invention relates to a method for shifting the instant of commutation for a sensorless and brushless direct-current motor whose stator windings are fed by a multi-phase converter connection.

Background Information

German Published Patent Application No. 39 40 568.9 describes a circuit configuration for operating a multi-phase synchronous motor at a direct-current supply. In this context, the phases are successively connected to the direct voltage and commutating circuits corresponding to the rotor position are controlled in such a manner that they overlap with respect to time for commutating subsequent phases, and at least one of the commutating circuits in the commutation range is clocked in such a manner that the average value of the current increases in the forward commutating phase and decreases in the reverse commutating phase. As a result of this overlapping and clocking of the switching signals in the commutation edges, there is less switching loss and a reduction in noise.

For sensorless and brushless direct-current motors, the instant of commutation is typically determined by measuring the induced voltage in a particular non-current carrying stator winding phase. In this context, this induced voltage is compared to a reference voltage that is derived from the actual value of the rotational speed. In this connection, significant power notches and ripples in the torque can occur, particularly in the case of large loads and high motor speeds. This is extremely disadvantageous.

The object of the present invention is to provide a method that enables the instant of

commutation to be shifted for a sensorless and brushless direct-current motor so as to prevent or significantly reduce the power notch, and decrease the torque ripple.

Summary Of The Invention

With respect to the related art, the method according to the present invention for shifting the instant of commutation for a sensorless and brushless direct-current motor has the advantage of an increase in power with a constant magnetic circuit and identical motor mechanics, and of a reduction in the torque ripple by adapting the commutation threshold to an optimum current waveform. Advantageously, there is also no power notch observed, as is in the case of a commutation shift dependent on the measured motor speed.

In the method according to the present invention, this is principally achieved in that commutation is detected by comparing the voltage induced in a non-energized stator winding phase to a reference voltage, and in that the reference voltage is changed in dependence upon the setpoint value of the motor speed and/or the manipulated variable calculated therefrom.

According to a particularly advantageous and preferred specific embodiment of the method according to the present invention, the instant of commutation is shifted ahead with respect to time in such a manner that an optimum current waveform is achieved, i.e., optimum particularly with regard to an increase in power and/or a reduction in the torque ripple.

According to a particularly effective and advantageous embodiment and further refinement of the method according to the present invention, the instant of commutation is shifted in such a manner that the reference voltage is raised in the shape of a parabola.

In a further advantageous embodiment of this method feature, given a pulse width modulation of the current supplied to the stator windings, the reference voltage is raised in the shape of a parabola, beginning at a pulse width modulation ratio of about 90 to 95%, in particular 93%. Raising the commutation threshold in the shape of a parabola has the advantage that it results in a smoother transition to the pre-commutation state.

According to a further advantageous feature of an exemplary embodiment of the method according to the present invention, besides being used for changing the reference value for the instant of commutation, the manipulated variable determined in dependence upon the setpoint value of the rotational speed is also used for adapting the current supply to the individual stator winding phases, raising it or lowering it accordingly.

A preferred system for implementing the above-explained method with its different modifications includes a sensorless and brushless direct-current motor that is fed by a multi-stage converter connection, which, for its part, includes an output stage control, a commutation logic, a phase selector, and a phase discriminator, and is characterized in that a commutation detection is provided which is supplied at one input by the phase selector with the instantaneous value of the voltage induced in a non-energized phase and, at a second input, with a reference voltage, for comparison, and in that the reference voltage can be changed by a commutation shift in accordance with a specific curve, a manipulated variable being supplied to the commutation shift by a manipulated-variable calculation as a function of the setpoint speed of the motor.

In an advantageous embodiment of this system according to the present invention, it is provided that in the commutation shift, the reference voltage changes in accordance with a parabola, in particular, it is increased.

Given a pulse width modulation of the current supply to the individual stator winding phases of the motor, one advantageous embodiment of this system configuration provides that the reference voltage is increased in the shape of a parabola, starting from a pulse width modulation ratio of about 90 to 95%, preferably 93%. These percent values apply for a specific magnetic circuit design. Other designs of the magnetic circuit can result in significantly different values.

In a further advantageous and particularly effective configuration of the system according to the present invention, calculating the manipulated variable yields, as a non-linear function of the setpoint speed of the motor, a manipulated variable that, on the one hand, is supplied to the commutation shift as an input, and, one the other hand, is supplied to the commutation

logic for adapting the current supply to the stator winding phases of the motor.

Brief Description Of The Drawings

Figure 1 shows a schematic block diagram for the commutation shift according to the present invention.

Figure 2 shows a diagram having the reference voltage as a function of the manipulated variable and/or the current in parabolic dependency.

Figure 3 shows different diagrams of the voltage curve of the induced voltage in one phase and of the current energization of this phase, and three different current waveforms for different reference voltages and different motor speeds, in general, current waveforms for different commutation thresholds.

Detailed Description

In a block diagram, Figure 1 represents the commutation shift according to the present invention. A direct-current motor 1, which is sensorless and brushless, is fed by a multi-stage converter connection. For its part, this multi-stage converter connection, which can be three-phased and six-pulsed, for example, includes an output stage control 2, a commutation logic 3, a phase selector 4, a phase discriminator 5, as well as a commutation detection 6 as the main components. A MOSFET transistor 22 is symbolically represented in output stage control 2. The output stage control supplies motor 1 with energy via a multiple line 21. Branching off of these lines, the respective instantaneous value of the voltage induced in a non-current-carrying phase is supplied via one multiple line 23, one of the, for example, six phases being selected in each case for this purpose by phase selector 4. This instantaneous value of the respective phase is transmitted by phase selector 4 via line 46 to a first input of commutation detection 6. A reference voltage U_{ref}, which is formed from adding the battery voltage supplied to motor 1 to the voltage from the commutation shift, is fed via line 47 to a second input of the commutation detection.

For its part, commutation shift 7 is supplied by a manipulated-variable calculation 8 via a line 87 with a manipulated variable U_{st}. Setpoint value $N_{setpoint}$ of the rotational speed of motor 1 is available as an input value via line 80 for manipulated-variable calculation 8. Manipulated variable U_{st} is determined in accordance with non-linear curve 81, which is represented in manipulated-variable calculation block 8, from this setpoint variable $N_{setpoint}$. This characteristic curve 81 is manipulated variable U_{st}, which is to be plotted over speed setpoint $N_{setpoint}$. Entered in block 7 of the commutation shift is a characteristic image in which manipulated variable U_{st} obtained in block 8 is plotted on the horizontal axis, and reference voltage U_{ref} is plotted on the vertical axis as a function thereof. The plotted characteristic curve 71 is preferably parabolic. The output value of manipulated-variable calculation 8 is fed via a line 83 to commutation logic 3 to increase the currents for output stage control 2 and the power transistors 22 contained therein, in correspondence with the predefined rotational speed $N_{setpoint}$ in the commutation logic, the currents then being supplied with the correct timing via lines 21 to motor 1.

The clock-pulse generation for commutation logic 3 is carried out by phase discriminator 5, which, as an input on line 65, generates the result of the comparison of reference voltage U_{ref} on line 47 and the instantaneous, phase-induced phase voltage on line 46 by comparator 61 in commutation detection 6. The output signal of phase discriminator 5, which is characterized by six different phases of pulse generation within block 5, is supplied via line 52 to commutation logic 3 and via line 54 to phase selector 4. As a result, phase selector 4 is adjusted to the correct phase for the commutation detection.

Figure 2 provides another larger and more exact view of the characteristic curve represented in Figure 1 within commutation shift 7, in a slightly different shape. In this context, the percent value of the pulse width modulation is plotted on the horizontal axis, this corresponding to manipulated variable U_{st} for characteristic curve 71 within commutation shift 7 in Figure 1. Plotted on the vertical axis is reference voltage U_{ref}, which is supplied to commutation detection 6 via line 47. The parabolic characteristic curve of reference voltage U_{ref} begins to climb, namely in the shape of a parabola, starting at a pulse width modulation ratio of about 90%, especially 93%. This parabolic raising of the commutation threshold, i.e., of the reference voltage U_{ref} supplied via line 47, has the advantage that the transition to the

pre-commutation state is smooth. Pre-commutation state means that the instant of commutation is advanced from its usual temporal state to an early start.

Figure 3 shows different diagrams and different current waveforms for different commutation thresholds. In the top diagram designated as A, voltage U_{ind}, which is induced in a phase U, for example, is plotted over the electrical angle. U_{bat} designates the battery voltage of a motor vehicle or the normal voltage of a direct-current vehicle electrical distribution system of a motor vehicle. U_{ref1}, which is below the battery voltage, designates a first reference voltage, and U_{ref2} designates a second reference voltage that is significantly above the value of battery voltage U_{bat}. One can assume that voltage reference value U_{ref1} approximately corresponds to the value 0.00 in Figure 2, and voltage reference value U_{ref2} in Figure 3, diagram A approximately corresponds to the value 1.00 of reference value U_{ref} in Figure 2.

In diagram B of Figure 3, IU designates the on-time of the current for phase U. If commutation is performed to reference value U_{ref1}, the current and current waveform are plotted over time t in diagram C of Figure 3, the time corresponding, for this commutation threshold, to a setpoint speed of 1500 revolutions per minute, for example. Thus, current I_{115} approximates the current waveform that, together with the voltage induced in the same phase, causes the torque.

Plotted over time t in diagram D of Figure 3 is current waveform I_{130}, which ensues at a commutation threshold of voltage U_{ref1} in diagram A of Figure 3 and at a rotational speed of 3000 revolutions per minute. It is recognizable that the current can only slowly and weakly increase in this phase as a result of the winding inductance at hand.

Plotted over time t in diagram E of Figure 3 are the current and current waveform I_{230}, which ensues at a commutation threshold of U_{ref2} and at a rotational speed of 3000 revolutions per minute. It can be seen from the diagram that at the instant corresponding to voltage U_{ref1} in diagram A, current I_{230} is already built up to its full value, and, therefore, when the induced voltage increases, the full torque can be made immediately available for use.

In accordance with the present invention, the instant of commutation can change between

those values that are between the points corresponding to commutation threshold U_{ref1} and U_{ref2} in diagram A. As a result of the temporal shift forward, commutation is correspondingly prematurely ended by the current being correspondingly switched off, as can be clearly seen from diagram E of Figure 3.

The function of the method according to the present invention and of the system according to the present invention is explained using the example of a air-conditioner fan motor for use in a motor vehicle. This is represented in detail in Figure 1-3 and was already extensively described above. In this context, it is important that in the case of such a blower, the load and, as such, the phase current increase quadratically with the rotational speed. Thus, for example, current I_{115} in diagram C at 1500 revolutions/minute has a value of 3 amperes. Given a commutation to threshold value U_{ref1}, this current at 3000 revolution/minute has a value of 18 amperes according to diagram D in Figure 3. It is recognizable from this representation that the shift of the commutation threshold attains an optimum current waveform for all operating states, and, as such, a high torque in the case of a smaller torque ripple. Such an optimum current waveform is represented by current I_{230} in diagram E of Figure 3. As a result of such an optimum current waveform, the ohmic losses and the switching losses in the semiconductor circuit are kept as minimal as possible.

Due to the winding inductance, the phase current can only increase in a limited time. In the case of low rotational speeds, as is shown in diagram C of Figure 3 by current I_{115}, this effect is not significantly noticeable with respect to the function angle. First in the case of average to high rotational speeds of about 1500 to 3000 revolutions/minute, does the restricted current increase have a negative effect on the torque formation, the torque being $M = c\varphi * I$, because at the instant the full, induced voltage is reached, $U_{ind} \approx c * \varphi$, the phase current is not yet built up. In diagram D of Figure 3, this is particularly represented by and readily recognizable from current I_{130}. Shifting the commutation threshold having a reference voltage U_{ref} that is greater than operating voltage U_{bat}, as shown in diagram A of Figure 3, results in the phase current having already adjusted itself to its maximum value upon reaching the full, induced voltage U_{ind}. As a result, the maximum torque can also be attained. The continuous increase in the commutation threshold having value U_{ref} starting from a defined setpoint speed enables the torque to be increased with constant motor mechanics.

Given drive systems having sensors attached, such an increase in torque is not possible due to the fixedly predefined position of the sensor. For sensorless drive systems that function using commutation shifting dependent on the actual value of the rotational speed, the disadvantage is that the commutation threshold is lowered in the case of a break of the speed due to a load increase. The resulting cancellation of the pre-commutation causes additional breaks in the rotational speed. This worsens the matter.

In contrast, the present invention in which the commutation shift is coupled to the speed setpoint ensures that this effect does not occur. The method according to the present invention and the system for its implementation according to the present invention advantageously provide a power increase with a constant magnetic circuit and identical motor mechanics, decrease the torque ripple, prevent power notches, and ensure a smooth transition to the pre-commutation state by increasing the commutation threshold in the shape of a parabola. This is then particularly advantageous when the motor is used for application as a fan in motor vehicles, where the fan load increases quadratically with the rotational speed. In this case, the parabolic commutation shift is particularly advantageous for the smooth load transition.

Abstract Of The Disclosure

A method for shifting the instant of commutation for a sensorless and brushless direct-current motor, whose stator windings are fed by a multi-phase converter connection. The converter connection includes an output stage control, a commutation logic, a phase selector, and phase discriminator. A commutation detection is supplied at one input with the instantaneous value of the voltage induced in a phase, the instantaneous value being determined by the phase selector, and at a second input, with a reference voltage for comparison. The reference voltage can be changed by a commutation shift in correspondence with a specific characteristic curve. A manipulated variable is supplied by a manipulated-variable calculation to the commutation shift as a function of the setpoint speed of the motor. The commutation shift takes place in an advantageous manner in a parabola shape. As a result of the setpoint value-dependent commutation shift, a high torque is provided also in the case of high rotational speeds and a heavy load, and the torque ripple is kept to a minimum.

METHOD FOR SHIFTING THE INSTANT OF COMMUTATION FOR A SENSORLESS AND BRUSHLESS DIRECT-CURRENT MOTOR AS WELL AS A SYSTEM FOR IMPLEMENTING THE METHOD

Field Of The Invention

The present invention [starts out from] relates to a method for shifting the instant of commutation for a sensorless and brushless direct-current motor whose stator windings are fed by a multi-phase converter connection [according to the definition of the species in Claim 1 and also relates to a system for implementing this method according to Claim 6].

Background Information

DE] German Published Patent Application No. 39 40 568.9 [A1] describes a circuit configuration for operating a multi-phase synchronous motor at a direct-current supply. In this context, the phases are successively connected to the direct voltage and commutating circuits corresponding to the rotor position are controlled in such a manner that they overlap with respect to time for commutating subsequent phases, and at least one of the commutating circuits in the commutation range is clocked in such a manner that the average value of the current increases in the forward commutating phase and decreases in the reverse commutating phase. As a result of this overlapping and clocking of the switching signals in the commutation edges, there is less switching loss and a reduction in noise.

For sensorless and brushless direct-current motors, the instant of commutation is typically determined by measuring the induced voltage in a particular non-current carrying stator winding phase. In this context, this induced voltage is compared to a reference voltage that is derived from the actual value of the rotational speed. In this connection, significant power notches and ripples in the torque can occur, particularly in the case of large loads and high motor speeds. This is extremely disadvantageous.

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The object of the present invention is to provide a method that enables the instant of commutation to be shifted for a sensorless and brushless direct-current motor so as to prevent or significantly reduce the power notch, and decrease the torque ripple.

Summary [of the] Of The Invention

With respect to the related art, the method according to the present invention for shifting the instant of commutation for a sensorless and brushless direct-current motor [having the characteristic features of Claim 1] has the advantage of an increase in power with a constant magnetic circuit and identical motor mechanics, and of a reduction in the torque ripple by adapting the commutation threshold to an optimum current waveform. Advantageously, there is also no power notch observed, as is in the case of a commutation shift dependent on the measured motor speed.

In the method according to the present invention, this is principally achieved in that commutation is detected by comparing the voltage induced in a non-energized stator winding phase to a reference voltage, and in that the reference voltage is changed in dependence upon the setpoint value of the motor speed and/or the manipulated variable calculated therefrom.

[Advantageous further refinements and improvements of the method stated in Claim 1 are rendered possible by the measures specified in the additional method claims.]

According to a particularly advantageous and preferred specific embodiment of the method according to the present invention, the instant of commutation is shifted ahead with respect to time in such a manner that an optimum current waveform is achieved, i.e., optimum particularly with regard to an increase in power and/or a reduction in the torque ripple.

According to a particularly effective and advantageous embodiment and further refinement of the method according to the present invention, the instant of commutation is shifted in such a manner that the reference voltage is raised in the shape of a parabola.

In a further advantageous embodiment of this method feature, given a pulse width modulation

of the current supplied to the stator windings, the reference voltage is raised in the shape of a parabola, beginning at a pulse width modulation ratio of about 90 to 95%, in particular 93%. Raising the commutation threshold in the shape of a parabola has the advantage that it results in a smoother transition to the pre-commutation state.

According to a further advantageous feature of an exemplary embodiment of the method according to the present invention, besides being used for changing the reference value for the instant of commutation, the manipulated variable determined in dependence upon the setpoint value of the rotational speed is also used for adapting the current supply to the individual stator winding phases, raising it or lowering it accordingly.

A preferred system for implementing the above-explained method with its different modifications includes a sensorless and brushless direct-current motor that is fed by a multi-stage converter connection, which, for its part, includes an output stage control, a commutation logic, a phase selector, and a phase discriminator, and is characterized in that a commutation detection is provided which is supplied at one input by the phase selector with the instantaneous value of the voltage induced in a non-energized phase and, at a second input, with a reference voltage, for comparison, and in that the reference voltage can be changed by a commutation shift in accordance with a specific curve, a manipulated variable being supplied to the commutation shift by a manipulated-variable calculation as a function of the setpoint speed of the motor.

In an advantageous embodiment of this system according to the present invention, it is provided that in the commutation shift, the reference voltage changes in accordance with a parabola, in particular, it is increased.

Given a pulse width modulation of the current supply to the individual stator winding phases of the motor, one advantageous embodiment of this system configuration provides that the reference voltage is increased in the shape of a parabola, starting from a pulse width modulation ratio of about 90 to 95%, preferably 93%. These percent values apply for a specific magnetic circuit design. Other designs of the magnetic circuit can result in significantly different values.

In a further advantageous and particularly effective configuration of the system according to the present invention, calculating the manipulated variable yields, as a non-linear function of the setpoint speed of the motor, a manipulated variable that, on the one hand, is supplied to the commutation shift as an input, and, one the other hand, is supplied to the commutation logic for adapting the current supply to the stator winding phases of the motor.

Brief Description [of the] Of The Drawings [Drawing]

[The method according to the present invention and the system for implementing this method are more closely explained in the following description using an exemplary embodiment represented in the drawing. The figures show:]

Figure 1 shows a schematic block diagram for the commutation shift according to the present invention[;].

Figure 2 shows a diagram having the reference voltage as a function of the manipulated variable and/or the current in parabolic dependency[; and].

Figure 3 shows different diagrams of the voltage curve of the induced voltage in one phase and of the current energization of this phase, and three different current waveforms for different reference voltages and different motor speeds, in general, current waveforms for different commutation thresholds.

Detailed Description [of the Exemplary Embodiment]

In a block diagram, Figure 1 represents the commutation shift according to the present invention. A direct-current motor 1, which is sensorless and brushless, is fed by a multi-stage converter connection. For its part, this multi-stage converter connection, which can be three-phased and six-pulsed, for example, includes an output stage control 2, a commutation logic 3, a phase selector 4, a phase discriminator 5, as well as a commutation detection 6 as the main components. A MOSFET transistor 22 is symbolically represented in output stage control 2. The output stage control supplies motor 1 with energy via a multiple line 21.

Branching off of these lines, the respective instantaneous value of the voltage induced in a non-current-carrying phase is supplied via one multiple line 23, one of the, for example, six phases being selected in each case for this purpose by phase selector 4. This instantaneous value of the respective phase is transmitted by phase selector 4 via line 46 to a first input of commutation detection 6. A reference voltage U_{ref}, which is formed from adding the battery voltage supplied to motor 1 to the voltage from the commutation shift, is fed via line 47 to a second input of the commutation detection.

For its part, commutation shift 7 is supplied by a manipulated-variable calculation 8 via a line 87 with a manipulated variable U_{st}. Setpoint value $N_{setpoint}$ of the rotational speed of motor 1 is available as an input value via line 80 for manipulated-variable calculation 8. Manipulated variable U_{st} is determined in accordance with non-linear curve 81, which is represented in manipulated-variable calculation block 8, from this setpoint variable $N_{setpoint}$. This characteristic curve 81 is manipulated variable U_{st}, which is to be plotted over speed setpoint $N_{setpoint}$. Entered in block 7 of the commutation shift is a characteristic image in which manipulated variable U_{st} obtained in block 8 is plotted on the horizontal axis, and reference voltage U_{ref} is plotted on the vertical axis as a function thereof. The plotted characteristic curve 71 is preferably parabolic. The output value of manipulated-variable calculation 8 is fed via a line 83 to commutation logic 3 to increase the currents for output stage control 2 and the power transistors 22 contained therein, in correspondence with the predefined rotational speed $N_{setpoint}$ in the commutation logic, the currents then being supplied with the correct timing via lines 21 to motor 1.

The clock-pulse generation for commutation logic 3 is carried out by phase discriminator 5, which, as an input on line 65, generates the result of the comparison of reference voltage U_{ref} on line 47 and the instantaneous, phase-induced phase voltage on line 46 by comparator 61 in commutation detection 6. The output signal of phase discriminator 5, which is characterized by six different phases of pulse generation within block 5, is supplied via line 52 to commutation logic 3 and via line 54 to phase selector 4. As a result, phase selector 4 is adjusted to the correct phase for the commutation detection.

Figure 2 provides another larger and more exact view of the characteristic curve represented

in Figure 1 within commutation shift 7, in a slightly different shape. In this context, the percent value of the pulse width modulation is plotted on the horizontal axis, this corresponding to manipulated variable U_{st} for characteristic curve 71 within commutation shift 7 in Figure 1. Plotted on the vertical axis is reference voltage U_{ref}, which is supplied to commutation detection 6 via line 47. The parabolic characteristic curve of reference voltage U_{ref} begins to climb, namely in the shape of a parabola, starting at a pulse width modulation ratio of about 90%, especially 93%. This parabolic raising of the commutation threshold, i.e., of the reference voltage U_{ref} supplied via line 47, has the advantage that the transition to the pre-commutation state is smooth. Pre-commutation state means that the instant of commutation is advanced from its usual temporal state to an early start.

Figure 3 shows different diagrams and different current waveforms for different commutation thresholds. In the top diagram designated as A, voltage U_{ind}, which is induced in a phase U, for example, is plotted over the electrical angle. U_{bat} designates the battery voltage of a motor vehicle or the normal voltage of a direct-current vehicle electrical distribution system of a motor vehicle. U_{ref1}, which is below the battery voltage, designates a first reference voltage, and U_{ref2} designates a second reference voltage that is significantly above the value of battery voltage U_{bat}. One can assume that voltage reference value U_{ref1} approximately corresponds to the value 0.00 in Figure 2, and voltage reference value U_{ref2} in Figure 3, diagram A approximately corresponds to the value 1.00 of reference value U_{ref} in Figure 2.

In diagram B of Figure 3, IU designates the on-time of the current for phase U. If commutation is performed to reference value U_{ref1}, the current and current waveform are plotted over time t in diagram C of Figure 3, the time corresponding, for this commutation threshold, to a setpoint speed of 1500 revolutions per minute, for example. Thus, current I_{115} approximates the current waveform that, together with the voltage induced in the same phase, causes the torque.

Plotted over time t in diagram D of Figure 3 is current waveform I_{130}, which ensues at a commutation threshold of voltage U_{ref1} in diagram A of Figure 3 and at a rotational speed of 3000 revolutions per minute. It is recognizable that the current can only slowly and weakly increase in this phase as a result of the winding inductance at hand.

Plotted over time t in diagram E of Figure 3 are the current and current waveform I_{230}, which ensues at a commutation threshold of U_{ref2} and at a rotational speed of 3000 revolutions per minute. It can be seen from the diagram that at the instant corresponding to voltage U_{ref1} in diagram A, current I_{230} is already built up to its full value, and, therefore, when the induced voltage increases, the full torque can be made immediately available for use.

In accordance with the present invention, the instant of commutation can change between those values that are between the points corresponding to commutation threshold U_{ref1} and U_{ref2} in diagram A. As a result of the temporal shift forward, commutation is correspondingly prematurely ended by the current being correspondingly switched off, as can be clearly seen from diagram E of Figure 3.

The function of the method according to the present invention and of the system according to the present invention is explained using the example of a air-conditioner fan motor for use in a motor vehicle. This is represented in detail in Figure 1-3 and was already extensively described above. In this context, it is important that in the case of such a blower, the load and, as such, the phase current increase quadratically with the rotational speed. Thus, for example, current I_{115} in diagram C at 1500 revolutions/minute has a value of 3 amperes. Given a commutation to threshold value U_{ref1}, this current at 3000 revolution/minute has a value of 18 amperes according to diagram D in Figure 3. It is recognizable from this representation that the shift of the commutation threshold [is necessary to] attains an optimum current waveform for all operating states, and, as such, a high torque in the case of a smaller torque ripple. Such an optimum current waveform is represented by current I_{230} in diagram E of Figure 3. As a result of such an optimum current waveform, the ohmic losses and the switching losses in the semiconductor circuit are kept as minimal as possible.

Due to the winding inductance, the phase current can only increase in a limited time. In the case of low rotational speeds, as is shown in diagram C of Figure 3 by current I_{115}, this effect is not significantly noticeable with respect to the function angle. First in the case of average to high rotational speeds of about 1500 to 3000 revolutions/minute, does the restricted current increase have a negative effect on the torque formation, the torque being $M = c\varphi * I$, because at the instant the full, induced voltage is reached, $U_{ind} \approx c * \varphi$, the phase current is not yet

built up. In diagram D of Figure 3, this is particularly represented by and readily recognizable from current I_{130}. Shifting the commutation threshold having a reference voltage U_{ref} that is greater than operating voltage U_{bat}, as shown in diagram A of Figure 3, results in the phase current having already adjusted itself to its maximum value upon reaching the full, induced voltage U_{ind}. As a result, the maximum torque can also be attained. The continuous increase in the commutation threshold having value U_{ref} starting from a defined setpoint speed enables the torque to be increased with constant motor mechanics.

Given drive systems having sensors attached, such an increase in torque is not possible due to the fixedly predefined position of the sensor. For sensorless drive systems that function using commutation shifting dependent on the actual value of the rotational speed, the disadvantage is that the commutation threshold is lowered in the case of a break of the speed due to a load increase. The resulting cancellation of the pre-commutation causes additional breaks in the rotational speed. This worsens the matter.

In contrast, the present invention in which the commutation shift is coupled to the speed setpoint ensures that this effect does not occur. The method according to the present invention and the system for its implementation according to the present invention advantageously provide a power increase with a constant magnetic circuit and identical motor mechanics, decrease the torque ripple, prevent power notches, and ensure a smooth transition to the pre-commutation state by increasing the commutation threshold in the shape of a parabola. This is then particularly advantageous when the motor is used for application as a fan in motor vehicles, where the fan load increases quadratically with the rotational speed. In this case, the parabolic commutation shift is particularly advantageous for the smooth load transition.

Abstract Of The Disclosure

A [The present invention provides a] method for shifting the instant of commutation for a sensorless and brushless direct-current motor[(1)], whose stator windings are fed by a multi-phase converter connection. The converter connection includes an output stage control[(2)], a commutation logic[(3)], a phase selector[(4)], and phase discriminator[(5)]. A commutation detection [(6)] is supplied at one input [(46)] with the instantaneous value of the voltage induced in a phase, the instantaneous value being determined by the phase selector, and at a second input[(47)], with a reference voltage [(Uref)] for comparison. The reference voltage [(Uref)] can be changed by a commutation shift [(7)] in correspondence with a specific characteristic curve[(71)]. A manipulated variable [(Ust)] is supplied by a manipulated-variable calculation [(8)] to the commutation shift [(7)] as a function of the setpoint speed [(Nsetpoint)] of the motor. The commutation shift takes place in an advantageous manner in a parabola shape. As a result of the setpoint value-dependent commutation shift, a high torque is provided also in the case of high rotational speeds and a heavy load, and the torque ripple is kept to a minimum.

[(Figure 1 for publication).]

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METHOD FOR SHIFTING THE INSTANT OF COMMUTATION FOR A SENSORLESS AND BRUSHLESS DIRECT-CURRENT MOTOR AS WELL AS A SYSTEM FOR IMPLEMENTING THE METHOD

Background Information

The present invention starts out from a method for shifting the instant of commutation for a sensorless and brushless direct-current motor whose stator windings are fed by a multi-phase converter connection according to the definition of the species in Claim 1 and also relates to a system for implementing this method according to Claim 6.

DE 39 40 568.9 A1 describes a circuit configuration for operating a multi-phase synchronous motor at a direct-current supply. In this context, the phases are successively connected to the direct voltage and commutating circuits corresponding to the rotor position are controlled in such a manner that they overlap with respect to time for commutating subsequent phases, and at least one of the commutating circuits in the commutation range is clocked in such a manner that the average value of the current increases in the forward commutating phase and decreases in the reverse commutating phase. As a result of this overlapping and clocking of the switching signals in the commutation edges, there is less switching loss and a reduction in noise.

For sensorless and brushless direct-current motors, the instant of commutation is typically determined by measuring the induced voltage in a particular non-current carrying stator winding phase. In this context, this induced voltage is compared to a reference voltage that is derived from the actual value of the rotational speed. In this connection, significant power notches and ripples in the torque can occur, particularly in the case of large loads and high motor speeds. This is extremely disadvantageous.

The object of the present invention is to provide a method that enables the instant of commutation to be shifted for a sensorless and brushless direct-current motor so as to prevent or significantly reduce the power notch, and decrease the torque ripple.

Summary of the Invention

With respect to the related art, the method according to the present invention for shifting the instant of commutation for a sensorless and brushless direct-current motor having the characteristic features of Claim 1 has the advantage of an increase in power with a constant magnetic circuit and identical motor mechanics, and of a reduction in the torque ripple by adapting the commutation threshold to an optimum current waveform. Advantageously, there is also no power notch observed, as is in the case of a commutation shift dependent on the measured motor speed.

In the method according to the present invention, this is principally achieved in that commutation is detected by comparing the voltage induced in a non-energized stator winding phase to a reference voltage, and in that the reference voltage is changed in dependence upon the setpoint value of the motor speed and/or the manipulated variable calculated therefrom.

Advantageous further refinements and improvements of the method stated in Claim 1 are rendered possible by the measures specified in the additional method claims.

According to a particularly advantageous and preferred specific embodiment of the method according to the present invention, the instant of commutation is shifted ahead with respect to time in such a manner that an optimum current waveform is achieved, i.e., optimum particularly with regard to an increase in power and/or a reduction in the torque ripple.

According to a particularly effective and advantageous embodiment and further refinement of the method according to the present invention, the instant of commutation is shifted in such a manner that the reference voltage is raised in the shape of a parabola.

In a further advantageous embodiment of this method feature, given a pulse width modulation of the current supplied to the stator windings, the reference voltage is raised in the shape of a parabola, beginning at a pulse width modulation ratio of about 90 to 95%, in particular 93%. Raising the commutation threshold in the shape of a parabola has the advantage that it results in a smoother transition to the pre-commutation state.

According to a further advantageous feature of an exemplary embodiment of the method according to the present invention, besides being used for changing the reference value for the instant of commutation, the manipulated variable determined in dependence upon the setpoint value of the rotational speed is also used for adapting the current supply to the individual stator winding phases, raising it or lowering it accordingly.

A preferred system for implementing the above-explained method with its different modifications includes a sensorless and brushless direct-current motor that is fed by a multi-stage converter connection, which, for its part, includes an output stage control, a commutation logic, a phase selector, and a phase discriminator, and is characterized in that a commutation detection is provided which is supplied at one input by the phase selector with the instantaneous value of the voltage induced in a non-energized phase and, at a second input, with a reference voltage, for comparison, and in that the reference voltage can be changed by a commutation shift in accordance with a specific curve, a manipulated variable being supplied to the commutation shift by a manipulated-variable calculation as a function of the setpoint speed of the motor.

In an advantageous embodiment of this system according to the present invention, it is provided that in the commutation shift, the reference voltage changes in accordance with a parabola, in particular, it is increased.

Given a pulse width modulation of the current supply to the individual stator winding phases of the motor, one advantageous embodiment of this system configuration provides that the reference voltage is increased in the shape of a parabola, starting from a pulse width modulation ratio of about 90 to 95%, preferably 93%. These percent values apply for a specific magnetic circuit design. Other designs of the magnetic circuit can result in significantly different values.

In a further advantageous and particularly effective configuration of the system according to the present invention, calculating the manipulated variable yields, as a non-linear function of the setpoint speed of the motor, a manipulated variable that, on the one hand, is supplied to the commutation shift as an input, and, one the other hand, is supplied to the commutation logic for adapting the current supply to the stator winding phases of the motor.

Brief Description of the Drawing

The method according to the present invention and the system for implementing this method are more closely explained in the following description using an exemplary embodiment represented in the drawing. The figures show:

Figure 1 shows a schematic block diagram for the commutation shift according to the present invention;

Figure 2 shows a diagram having the reference voltage as a function of the manipulated variable and/or the current in parabolic dependency; and

Figure 3 shows different diagrams of the voltage curve of the induced voltage in one phase and of the current energization of this phase, and three different current waveforms for different reference voltages and different motor speeds, in general, current waveforms for different commutation thresholds.

Description of the Exemplary Embodiment

In a block diagram, Figure 1 represents the commutation shift according to the present invention. A direct-current motor 1, which is sensorless and brushless, is fed by a multi-stage converter connection. For its part, this multi-stage converter connection, which can be three-phased and six-pulsed, for example, includes an output stage control 2, a commutation logic 3, a phase selector 4, a phase discriminator 5, as well as a commutation detection 6 as the main components. A MOSFET transistor 22 is symbolically represented in output stage control 2. The output stage control supplies motor 1 with energy via a multiple line 21. Branching off of these lines, the respective instantaneous value of the voltage induced in a non-current-carrying phase is supplied via one multiple line 23, one of the, for example, six phases being selected in each case for this purpose by phase selector 4. This instantaneous value of the respective phase is transmitted by phase selector 4 via line 46 to a first input of commutation detection 6. A reference voltage U_{ref}, which is formed from adding the battery voltage supplied to motor 1 to the voltage from the commutation shift, is fed via line 47 to a second input of the commutation detection.

For its part, commutation shift 7 is supplied by a manipulated-variable calculation 8 via a line 87 with a manipulated variable U_{st}. Setpoint value $N_{setpoint}$ of the rotational speed of motor 1 is available as an input value via line 80 for manipulated-variable calculation 8. Manipulated variable U_{st} is determined in accordance with non-linear curve 81, which is represented in manipulated-variable calculation block 8, from this setpoint variable $N_{setpoint}$. This characteristic curve 81 is manipulated variable U_{st}, which is to be plotted over speed setpoint $N_{setpoint}$. Entered in block 7 of the commutation shift is a characteristic image in which manipulated variable U_{st} obtained in block 8 is plotted on the horizontal axis, and reference voltage U_{ref} is plotted on the vertical axis as a function thereof. The plotted characteristic curve 71 is preferably parabolic. The output value of manipulated-variable calculation 8 is fed via a line 83 to commutation logic 3 to increase the currents for output stage control 2 and the power transistors 22 contained therein, in correspondence with the predefined rotational speed $N_{setpoint}$ in the commutation logic, the currents then being supplied with the correct timing via lines 21 to motor 1.

The clock-pulse generation for commutation logic 3 is carried out by phase discriminator 5, which, as an input on line 65, generates the result of the comparison of reference voltage U_{ref} on line 47 and the instantaneous, phase-induced phase voltage on line 46 by comparator 61 in commutation detection 6. The output signal of phase discriminator 5, which is characterized by six different phases of pulse generation within block 5, is supplied via line 52 to commutation logic 3 and via line 54 to phase selector 4. As a result, phase selector 4 is adjusted to the correct phase for the commutation detection.

Figure 2 provides another larger and more exact view of the characteristic curve represented in Figure 1 within commutation shift 7, in a slightly different shape. In this context, the percent value of the pulse width modulation is plotted on the horizontal axis, this corresponding to manipulated variable U_{st} for characteristic curve 71 within commutation shift 7 in Figure 1. Plotted on the vertical axis is reference voltage U_{ref}, which is supplied to commutation detection 6 via line 47. The parabolic characteristic curve of reference voltage U_{ref} begins to climb, namely in the shape of a parabola, starting at a pulse width modulation ratio of about 90%, especially 93%. This parabolic raising of the commutation threshold, i.e., of the reference voltage U_{ref} supplied via line 47, has the advantage that the transition to the pre-commutation state is smooth. Pre-commutation state means that the instant of

commutation is advanced from its usual temporal state to an early start.

Figure 3 shows different diagrams and different current waveforms for different commutation thresholds. In the top diagram designated as A, voltage U_{ind}, which is induced in a phase U, for example, is plotted over the electrical angle. U_{bat} designates the battery voltage of a motor vehicle or the normal voltage of a direct-current vehicle electrical distribution system of a motor vehicle. U_{ref1}, which is below the battery voltage, designates a first reference voltage, and U_{ref2} designates a second reference voltage that is significantly above the value of battery voltage U_{bat}. One can assume that voltage reference value U_{ref1} approximately corresponds to the value 0.00 in Figure 2, and voltage reference value U_{ref2} in Figure 3, diagram A approximately corresponds to the value 1.00 of reference value U_{ref} in Figure 2.

In diagram B of Figure 3, IU designates the on-time of the current for phase U. If commutation is performed to reference value U_{ref1}, the current and current waveform are plotted over time t in diagram C of Figure 3, the time corresponding, for this commutation threshold, to a setpoint speed of 1500 revolutions per minute, for example. Thus, current I_{115} approximates the current waveform that, together with the voltage induced in the same phase, causes the torque.

Plotted over time t in diagram D of Figure 3 is current waveform I_{130}, which ensues at a commutation threshold of voltage U_{ref1} in diagram A of Figure 3 and at a rotational speed of 3000 revolutions per minute. It is recognizable that the current can only slowly and weakly increase in this phase as a result of the winding inductance at hand.

Plotted over time t in diagram E of Figure 3 are the current and current waveform I_{230}, which ensues at a commutation threshold of U_{ref2} and at a rotational speed of 3000 revolutions per minute. It can be seen from the diagram that at the instant corresponding to voltage U_{ref1} in diagram A, current I_{230} is already built up to its full value, and, therefore, when the induced voltage increases, the full torque can be made immediately available for use.

In accordance with the present invention, the instant of commutation can change between those values that are between the points corresponding to commutation threshold U_{ref1} and U_{ref2} in diagram A. As a result of the temporal shift forward, commutation is correspondingly

prematurely ended by the current being correspondingly switched off, as can be clearly seen from diagram E of Figure 3.

The function of the method according to the present invention and of the system according to the present invention is explained using the example of a air-conditioner fan motor for use in a motor vehicle. This is represented in detail in Figure 1-3 and was already extensively described above. In this context, it is important that in the case of such a blower, the load and, as such, the phase current increase quadratically with the rotational speed. Thus, for example, current I_{115} in diagram C at 1500 revolutions/minute has a value of 3 amperes. Given a commutation to threshold value U_{refl}, this current at 3000 revolution/minute has a value of 18 amperes according to diagram D in Figure 3. It is recognizable from this representation that the shift of the commutation threshold is necessary to attain an optimum current waveform for all operating states, and, as such, a high torque in the case of a smaller torque ripple. Such an optimum current waveform is represented by current I_{230} in diagram E of Figure 3. As a result of such an optimum current waveform, the ohmic losses and the switching losses in the semiconductor circuit are kept as minimal as possible.

Due to the winding inductance, the phase current can only increase in a limited time. In the case of low rotational speeds, as is shown in diagram C of Figure 3 by current I_{115}, this effect is not significantly noticeable with respect to the function angle. First in the case of average to high rotational speeds of about 1500 to 3000 revolutions/minute, does the restricted current increase have a negative effect on the torque formation, the torque being $M = c\varphi * I$, because at the instant the full, induced voltage is reached, $U_{ind} \approx c * \varphi$, the phase current is not yet built up. In diagram D of Figure 3, this is particularly represented by and readily recognizable from current I_{130}. Shifting the commutation threshold having a reference voltage U_{ref} that is greater than operating voltage U_{bat}, as shown in diagram A of Figure 3, results in the phase current having already adjusted itself to its maximum value upon reaching the full, induced voltage U_{ind}. As a result, the maximum torque can also be attained. The continuous increase in the commutation threshold having value U_{ref} starting from a defined setpoint speed enables the torque to be increased with constant motor mechanics.

Given drive systems having sensors attached, such an increase in torque is not possible due to the fixedly predefined position of the sensor. For sensorless drive systems that function using

commutation shifting dependent on the actual value of the rotational speed, the disadvantage is that the commutation threshold is lowered in the case of a break of the speed due to a load increase. The resulting cancellation of the pre-commutation causes additional breaks in the rotational speed. This worsens the matter.

In contrast, the present invention in which the commutation shift is coupled to the speed setpoint ensures that this effect does not occur. The method according to the present invention and the system for its implementation according to the present invention advantageously provide a power increase with a constant magnetic circuit and identical motor mechanics, decrease the torque ripple, prevent power notches, and ensure a smooth transition to the pre-commutation state by increasing the commutation threshold in the shape of a parabola. This is then particularly advantageous when the motor is used for application as a fan in motor vehicles, where the fan load increases quadratically with the rotational speed. In this case, the parabolic commutation shift is particularly advantageous for the smooth load transition.

What is claimed is:

1. A method for shifting the instant of commutation for a sensorless and brushless direct-current motor (1), whose stator windings are fed by a multi-phase converter connection,
wherein commutation is detected by comparing the voltage induced in a stator winding phase in which no current is applied, to a reference voltage (U_{ref}), and the reference voltage (U_{ref}) is changed in dependence upon the setpoint value ($N_{setpoint}$) of the rotational speed of the motor (1) and/or the manipulated variable (U_{st}) calculated therefrom.

2. The method as recited in Claim 1,
wherein the instant of commutation is shifted forward with respect to time in such a manner that an optimum current waveform is achieved, i.e., optimum particularly with respect to increasing the power and/or reducing the torque ripple.

3. The method as recited in Claim 1 or 2,
wherein the instant of commutation is shifted in such a manner that the reference voltage (U_{ref}) is raised in the shape of a parabola.

4. The method as recited in Claim 3,
wherein given a pulse width modulation of the current supplied to the stator windings, the parabola-shaped raising of the reference voltage begins at a pulse width modulation ratio of about 90 to 95%, in particular 93%.

5. The method as recited in Claim 1 or in one of Claims 2 through 4,
wherein besides being used for changing the reference value for the instant of commutation, the manipulated variable (U_{st}) determined in dependence upon the setpoint value ($N_{setpoint}$) of the rotational speed is also used for adapting the current supply to the individual stator winding phases, raising it or lowering it accordingly.

6. A system for implementing the method as recited in Claim 1 or in one of Claims 2 through 5, having a sensorless and brushless direct-current motor (1), which is fed by

a multi-stage converter connection, which, for its part, includes an output stage control (2), a commutation logic (3), a phase selector (4), and a phase discriminator (5), wherein a commutation detection (6) is provided which is supplied at one input (46) by the phase selector (4) with the instantaneous value of the voltage induced in a non-energized phase and, at a second input (47), with a reference voltage (U_{ref}), for comparison; and the reference voltage (U_{ref}) can be changed by a commutation shift (7) in accordance with a specific curve, a manipulated variable (U_{st}) being supplied to the commutation shift (7) by a manipulated-variable calculation (8) as a function of the setpoint speed ($N_{setpoint}$) of the motor (1).

7. The system as recited in Claim 6, wherein in the commutation shift (7), the reference voltage (U_{ref}) is changed in accordance with a parabola, in particular increased.

8. The system as recited in Claim 7, wherein, given a pulse width modulation (PWM) of the current supply to the individual stator winding phases of the motor (1), the reference voltage (U_{ref}) is increased in a parabola shape, starting from a pulse width modulation ratio of about 90 to 95%, preferably 93%.

9. The system as recited in Claim 6 or in one of Claims 7 or 8, wherein the manipulated-variable calculation (8) computes a manipulated variable (U_{st}) as a non-linear function of the setpoint speed ($N_{setpoint}$) of the motor (1), this manipulated variable being fed, on the one hand (87), as an input to the commutation shift (7), and, on the other hand (83), to the commutation logic (3) to adapt the current supply to the stator winding phases of the motor (1).

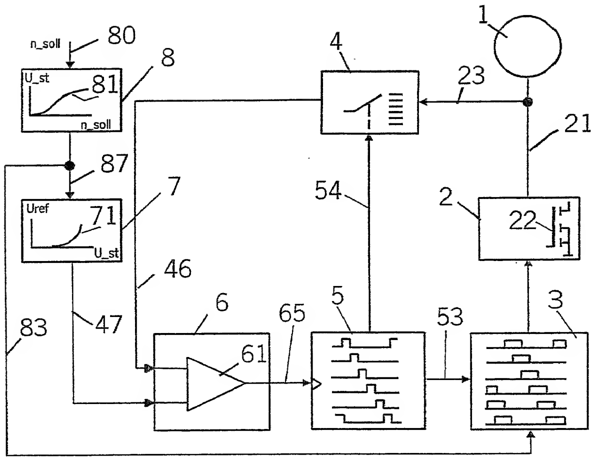
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FIG. 1

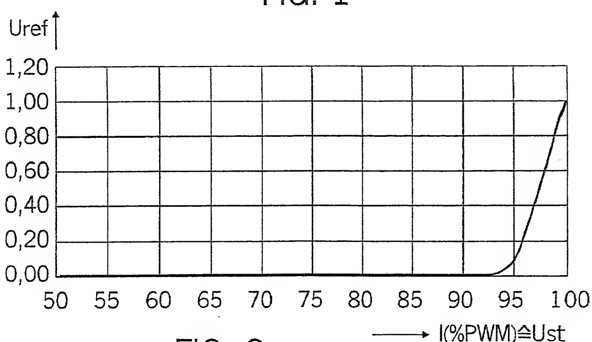
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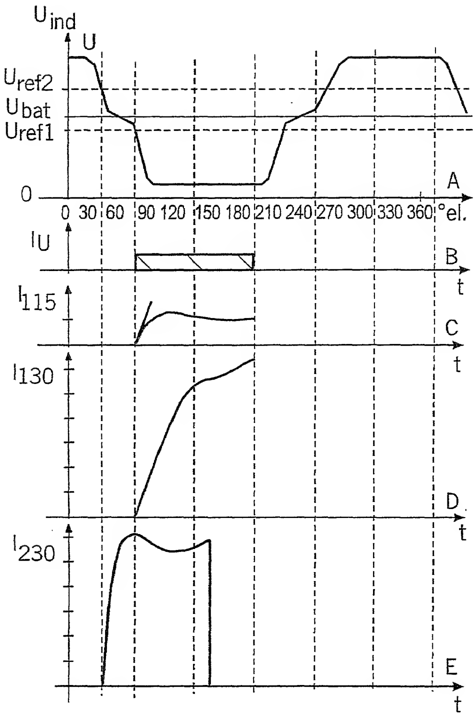
FIG. 2



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0 30 60 90 120 150 180 210 240 270 300 330 360 °el.
IU
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I115
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FIG. 3

3675

RS

[10191/1860]

COMBINED DECLARATION AND
POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below adjacent to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **METHOD FOR SHIFTING THE INSTANT OF COMMUTATION FOR A SENSORLESS AND BRUSHLESS DIRECT-CURRENT MOTOR AS WELL AS A SYSTEM FOR IMPLEMENTING THE METHOD**, and the specification of which:

[ ] is attached hereto;

[ ] was filed as United States Application Serial No.
and,

[X] was filed as PCT International Application Number PCT/DE00/04008, on the 10th day of November, 2000
[X] an English translation of which is filed herewith.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a). I hereby claim foreign priority benefits under Title 35, United States Code § 119 of any foreign application(s) for patent or inventor's certificate or of any PCT international applications(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

EL039798569US
~~EL244504926US~~

PRIOR FOREIGN/PCT APPLICATION(S)
AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. § 119

Country : Federal Republic of Germany

Application No. : 199 55 248.7

Date of Filing: 17 November 1999

Priority Claimed
Under 35 U.S.C. § 119 : [x] Yes [ ] No

I hereby claim the benefit under Title 35, United States Code § 120 of any United States Application or PCT International Application designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations § 1.56(a) which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application:

PRIOR U.S. APPLICATIONS OR
PCT INTERNATIONAL APPLICATIONS
DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. § 120

U.S. APPLICATIONS

Number :

Filing Date :

PCT APPLICATIONS
DESIGNATING THE U.S.

PCT Number :

PCT Filing Date :

I hereby appoint the following attorney(s) and/or agents to prosecute the above-identified application and transact all business in the Patent and Trademark Office connected therewith.

(List name(s) and registration number(s)):

2 —

Richard L. Mayer,	Reg. No. 22,490
Gerard A. Messina,	Reg. No. 35,952

All correspondence should be sent to:

Richard L. Mayer, Esq.
Kenyon & Kenyon
One Broadway
New York, New York 10004

Telephone No.: (212) 425-7200
Facsimile No.: (212) 425-5288

CUSTOMER NO. 26646

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

1-00 Full name of inventor **Joerg SUTTER**

Inventor's signature Jörg Sutter Date 22.08.01

Citizenship: Federal Republic of Germany

Residence: Mozartstraße 37
76571 Gaggenau
Federal Republic of Germany DEX

Post Office Address Same as above

2 - 60 Full name of inventor **Wolfgang SCHWENK**

Inventor's signature W. Schwenk Date 09/08/01

Citizenship: Federal Republic of Germany

Residence: Hubeneck 39
77704 Oberkirch-Tiergarten
Federal Republic of Germany DEX

Post Office Address Same as above